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GB	1340983	GB	1219822
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(58) Field of search
H1A

(54) Cryogenic cable and method of making same

(57) A cable for cryogenic use includes an inner conductor 30 and a solid polymeric insulator 38 e.g. of XPLE or EPR loosely positioned about the inner conductor 30 so that cooling of the cable does not result in damage caused by shrinkage of the insulator 38. A collapsible spacer 36 may be positioned between the inner conductor 30 and the polymeric insulator 38 to further space the insulator 38 away from the conductor 30. To make the cable, it is sealed and pressure, e.g. 2 atm or more, is applied to expand the insulator 38. The cable is placed inside a loosely fitting rigid cylinder (22, Fig. 2) which is heated to aid the expansion of the insulator 38, and then cooled whilst keeping the cable pressurized. The cable also comprises shields 34 and 40 of carbon impregnated polyethylene, and conductor 42. Collapsible spacer 36 may comprise hollow semiconducting or insulating tubes covered with a conducting fabric of e.g. PTFE, nylon or polyester, or with a foil. It may instead be a space or dielectric (55, fig. 5) bridged by conductive filaments (57, fig. 5) or a semiconducting foam (66, fig. 6), or crepe paper (74, fig. 7), or longitudinally corrugated metal alloy.

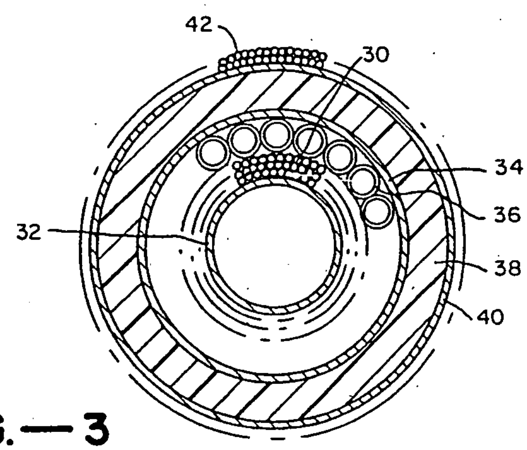

FIG.—3

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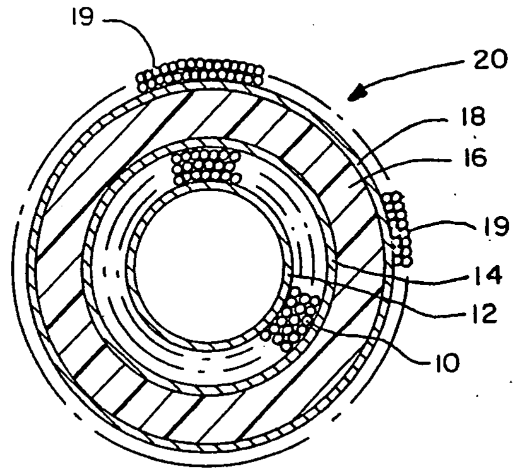

FIG.—1

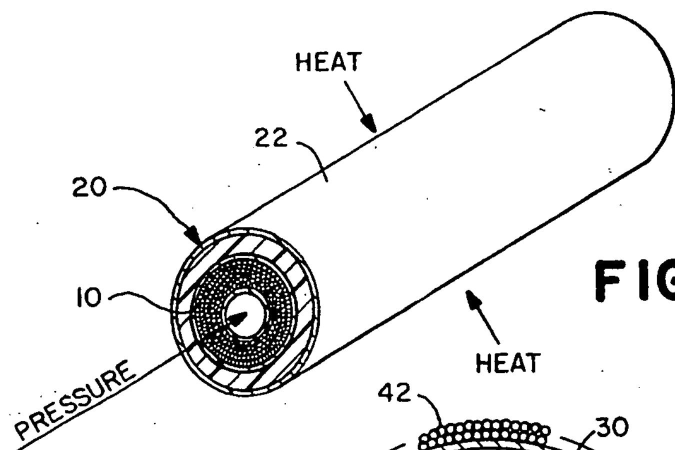

FIG.—2

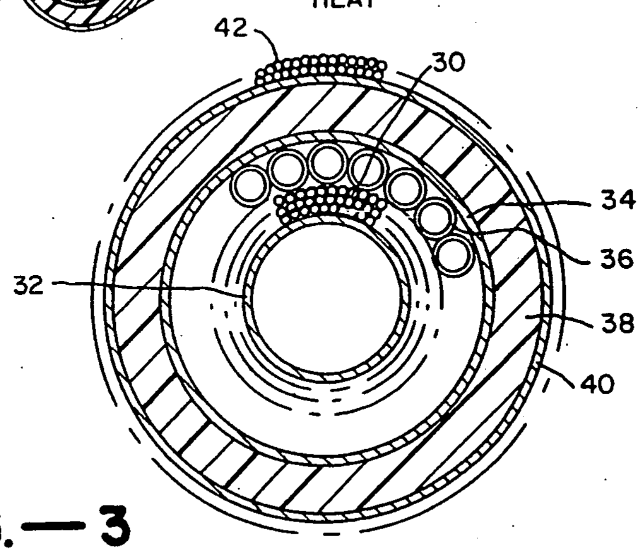

FIG.—3

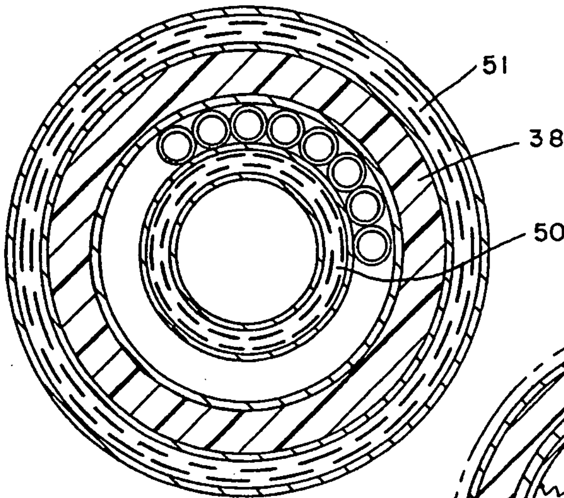

FIG. — 4

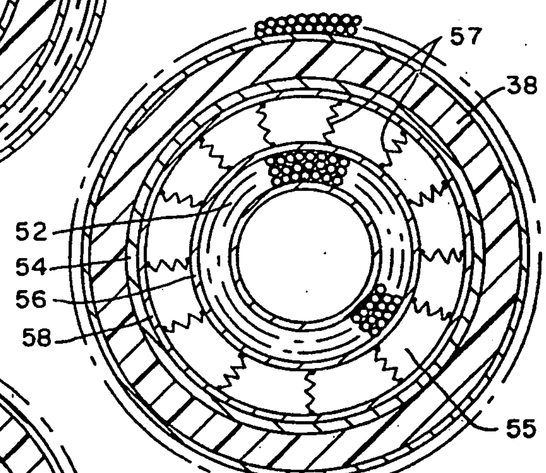

FIG. — 5

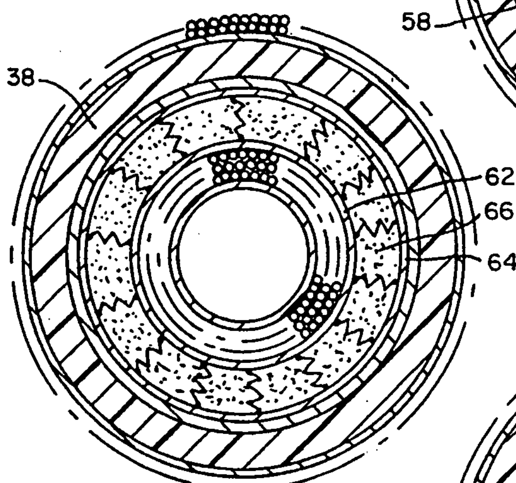

FIG. — 6

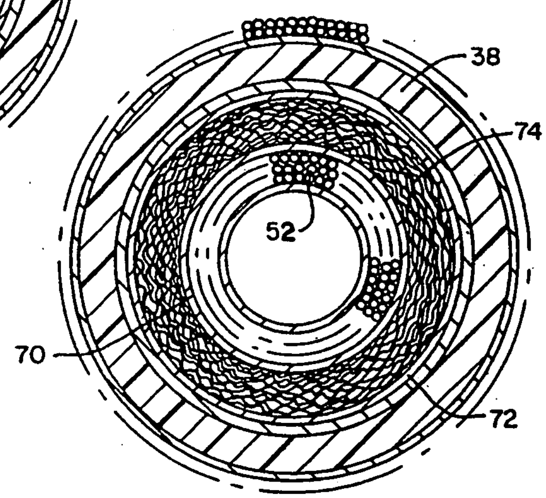

FIG. — 7

SPECIFICATION

Cryogenic cable and method of making same

This invention relates generally to high voltage electrical cables for cryogenic applications, and more particularly the invention relates to cryogenic cables having improved electrical insulation and to the method of manufacturing same.

The use of solid extruded polymeric insulative cables in ambient applications (e.g. at temperatures ranging from −50°C to +150°C) has heretofore been proposed. Experimental cables for cryogenic applications have been developed which utilize laminar insulation consisting of cellulose and/or polymeric papers or polymeric films impregnated with liquid nitrogen or helium along the butt-gaps. However, none of these insulation systems has provided the same level of dielectric strength as is obtainable with conventional paper-oil or extruded dielectric at room temperature. The relatively low dielectric strength of such laminar cryogenic cables is caused by the relatively low dielectric strength of the impregnants (nitrogen and especially helium) at temperatures close to their boiling temperatures.

The excellent insulation qualities of solid polymeric material have not been available in cryogenic applications due to difficulties arising from differences in coefficients of thermal expansion of the conductive material and the polymeric material and resulting destructive stresses in the polymeric material at cryogenic temperatures.

Accordingly, an object of the present invention is an improved cryogenic cable.

Another object of the invention is a cryogenic cable having improved electrical insulation.

Still another object of the invention is the method of treating a cable having solid polymeric insulation thereby eliminating the cryogen from the butt-gaps so that the cable can be used in cryogenic applications.

A feature of the invention is polymeric insulation which does not develop damaging stresses from shrinkage when cooled to cryogenic temperatures.

Another feature of the invention is a cryogenic high voltage cable having collapsible means for minimizing insulation stresses arising from shrinkage.

Briefly, a cable in accordance with one embodiment of the invention includes an inner conductor and a polymeric insulator about the conductor. The polymeric insulator is loosely positioned relative to the conductor whereby shrinkage of the insulation at temperatures in the cryogenic operation range does not create excessive stress

In providing the loose positioning of the insulation about the conductor in the cable, the cable is placed in a rigid cylinder or a pipe which has an inside diameter larger than the outside diameter of the cable. The pipe is heated and internal pressure is applied by means of gas through the stranded or taped conductor to the cable conductor shield and surrounding insulation whereby the conductor shield and insulation expands to the inside diameter of the pipe. The temperature of the pipe is then reduced while maintaining the pressure on the cable, thereby permanently stretching the conductor shield and polymeric insulator.

Although there is now present a void space between the central conductor and the conductor shield, this region is essentially electric field free and should cause no problems. This is because the conductor shield is conducting and the conductor touches it. Since they are at approximately the same potential, there is essentially no electric field between them.

In another embodiment of the invention, the cable can be provided with a plurality of collapsible bodies such as hollow semiconducting tubes which are positioned between the conductor and the conductor shield. In treating the cable for the extrusion expansion process the tubes are first pressurized before pressure is applied to the inner conductor whereby the applied pressure is transmitted to the conductor shield and insulation. Following the extrusion expansion and curing heat treatment and after relieving the applied pressure to the cable, pressure in the tubes is withdrawn.

The invention and objects and features thereof will be more readily apparent from the following detailed description and appended claims when taken with the drawing, in which:

Figure 1 is a section view of one embodiment of a cryogenic cable in accordance with the present invention.

Figure 2 is a perspective view illustrating the method of treating a cable in accordance with the invention.

Figures 3—7 are section views of other embodiments of a cryogenic cable in accordance with the invention.

Referring now to the drawing, Figure 1 is a cross section view of an electrical cable in accordance with one embodiment of the present invention. The cable shown generally at 20 includes an inner conductor comprising a plurality of strands 10 of a conductor such as copper which are assembled on a mandrel 12. Surrounding the conductive strands 10 is a conductor shield 14 comprising a material such as carbon impregnated polyethelene. Positioned about the conductor shield 14 is a body of insulation 16, and surrounding insulation 16 is an insulation shield 18 which also may comprise carbon impregnated polyethelene. The outer conductor 19 comprises a plurality of strands of conductive material.

In accordance with the present invention the insulative body 16 comprises a solid polymeric material such as cross linked polyethelene (XLPE) or ethylene propolene rubber (EPR). Heretofore, such insulation material could be used only in electrical cables operated under ambient conditions. In cryogenic applications the greater

coefficient of thermal expansion of the polymeric material compared to the conductor material would cause damaging stresses in the insulation as the cable is cooled down to cryogenic operating temperatures (e.g. 4°K).

In accordance with the present invention the solid polyethelene insulation layer is loosely positioned about the inner conductor at ambient temperatures (e.g. above 0°C). In a low voltage cable requiring only a thin layer of electrical insulation, the insulation material can be extruded loosely over the conductor. A conventional low pressure application technique such as sleeving can be utilized. One or more sleeves of polymeric material can be employed, and intimate bonding of adjacent polymer layer preferably is effected when a plurality of polymer sleeves are utilized. Improved sleeve insulation is provided by using inner and outer semi-conductor sleeves and an intermediate dielectric sleeve. The sleeves may be separately or simultaneously applied.

Greater shrinkage of the insulation without inducing damaging stresses therein can be accommodated through a fabrication process wherein the insulation is stretched prior to employment of the cable. Referring to Figure 2, the assembled cable shown generally at 20 is placed within a rigid cylinder 22 and one end of cable 20 is sealed. Thereafter, pressure of the order of two atmospheres or greater is applied through the mandrel 12 of cable 20 with the pressure transmitted through the conductor strands to the conductor shield and surrounding insulation by a relatively inert gas such as argon, neon or nitrogen. Heat on the order of 170°C is applied to the cable from an external source through cylinder 22 resulting in the conductor shield, insulation, and insulation shield expanding to contact the inner diameter of cylinder 22. Thereafter, the heat is removed from the assembly while the pressure within cable 20 is maintained thus allowing the insulation to set at a greater radius and spaced further from the inner conductor of the cable. Using the materials described with reference to Figure 1, pressure should be maintained until the temperature is reduced at least to approximately 85°C. Thereafter, the insulation of the cable will remain expanded beyond the diameter of the conductor without the need for pressure. Consequently, when the cable is cooled for operation at cryogenic temperatures no stress is induced in the insulation system by the conductor even though the insulation system contracts more than the conductor.

For high voltage cables requiring thicker insulation walls, a large radial space must be provided for the change in radial dimension of the insulation. Figure 3 is a cross section of another embodiment of an electrical cable which provides for increased shrinkage of a thick insulation wall. Again, a plurality of strands of conductor 30 are provided about a mandrel 32. Placed about the strands 30 and inside of the conductor shield 34 are a plurality of collapsible tubes 36 which are impregnated with semiconductor compounds, or covered with a conducting fabric, using materials like Teflon® (Teflon is an RTM), nylon, polyester or like material which is capable of withstanding the heat treatment described above. The solid polymeric insulation 38 surrounds the conductor shield 34, and an insulator shield 40 surrounds the insulation 38. Strands of the outer conductor 42 surround the shield 40.

The collapsible tubes can be made of semiconductor or insulating material. They may have other than round shape. In the case of insulating tubes they may be covered by a layer of conducting or semiconducting material. The conducting element could be a metallic braid or a fabric with a number of conducting filaments interwoven between insulating filaments or it could be covered by a foil.

In employing the process described above, the ends of tubes 36 are closed and the tubes 36 are pressurized prior to the application pressure through mandrel 32 to the table. Preferably, the tube pressure is provided by a liquid such as glycol, glycerol, silicone, or polyalkaline. The pressure within tubes 36 is preferably at least as high as the pressure applied to mandrel 32 whereby the pressure from mandrel 32 is transmitted through tubes 36 to the conductive shield 34, insulation 38, and insulation shield 40. Following the heat treatment and removal of cable pressure as above described, the pressure within tubes 36 is relieved thereby spacing the conductor shield and insulation away from the inner conductor.

Figure 4 is an alternative embodiment similar to Figure 3 but in which the inner conductor 50 is a superconductor in the form of two layers of tape, each of which is helically wound in opposite directions. The other components such as insulator 38 are similar to the components in Figure 3, except that superconducting tape 51 replaces the outer stranded conductor.

In Figure 5 the space between the inner conductor binder 52 and the semiconductive shield 54 is occupied by a hollow semiconducting tube 55 having an inner wall 56 and an outer wall 58. The inner wall 56 may be applied directly over the inner conductor 52, and shield 54 is applied over the outer wall 58. During application of the extruded insulation 38, the tube is filled with a suitable liquid (not shown). Conducting filaments 57 are provided between the two tube walls. After application of the extruded insulation, the liquid is removed from the tube thereby providing space for contraction of the insulation system during cooling of the cable.

Figure 6 is another embodiment in which the space between the inner conductor binder 62 and outer binder 64 is occupied by a foam spacer 66 of semiconducting materials or, alternatively, a dielectric provided with conductive filaments to connect the inner and outer binders. In Figure 7 the space between the inner and outer binders 70, 72 is filled with semiconducting crepe paper 74 which can compress radially during the cooling of

the insulation. Conductors 52 and insulator 38 are like the same elements in Figure 5.

In still other embodiments the inner and outer conductor binders can be separated by thin longitudinally corrugated spacers made of metal alloy which retains flexing characteristics down to very low temperatures. Further, the inner and outer conductor binders may be joined by a combination of one or more of the described systems, such as for example collapsible tubes and foam.

A cryogenic cable in accordance with the present invention wherein the central conductor is loose with respect to the conductor shield and insulation to accommodate shrinkage thereof for cryogenic operation of the conductor results in a structure having improved insulation since polymeric material can be employed.

While the invention has been described with reference to specific embodiments, the description is illustrative of the invention and is not to be construed as limiting the invention. For example, the plurality of tubes can be replaced by a single double walled tube. Other spacers can be used such as a foam spacer, crepe paper, or longitudinally corrugated spacers. Thus, various modifications and applications may occur to those skilled in the art without departing from the true scope and spirit of the invention as defined by the appended claims.

CLAIMS

1. A coaxial cryogenic electrical cable comprising an inner electrical conductor, a passage through said inner conductor for the flow of a coolant, a conductor shield surrounding said inner conductor, a solid polymeric electrical insulator surrounding said inner conductor and conductor shield, and an outer conductor surrounding said insulator, characterised in that said insulator is positioned away from said electrical conductor above 0°C whereby as cable temperature is lowered below 0°C said insulator can shrink without inducing damaging stresses in said insulator.

2. A cryogenic cable as defined by claim 1 and further including a conductor shield spaced from said inner conductor above 0°C.

3. A cryogenic electrical cable as defined by claim 1 and further including a collapsible spacer positioned between said inner conductor and said conductor shield.

4. A cryogenic electrical cable as defined by claim 3 wherein said collapsible spacer means comprises a plurality of hollow tubes.

5. A cryogenic electrical cable as defined by claim 3 and wherein said collapsible spacer means comprises foam material.

6. A cryogenic electrical cable as defined by claim 3 wherein said collapsible spacer means comprises conductive crepe paper.

7. A cryogenic electrical cable as defined by claim 3 wherein said collapsible spacer means comprises a double walled tube.

8. A method of making a coaxial cryogenic cable according to claim 1, wherein the cable is placed in a cylindrical space within a rigid member, the said space having an inside diameter which is larger than the outside diameter of the cable, the method including the steps of heating the rigid member and applying pressure within the cable so as to expand the conductor shield and the insulator until the outer surface of the cable touches the inner surface of the rigid member, reducing the temperature of the rigid member while maintaining the pressure within the cable, and relieving the pressure when the temperature of the rigid member has fallen to a predetermined value.

9. A method according to claim 8, wherein the cable is in accordance with claim 3, and the method includes pressurising the collapsible spacer so that the pressure applied within the cable is transmitted to the conductor shield and the insulator, and relieving the pressure in the collapsible spacer after the temperature has fallen to the said predetermined value.

10. A coaxial cryogenic cable having a solid polymeric insulator loosely positioned about the inner conductor above 0°C.

11. A coaxial cryogenic cable substantially as described hereinbefore with reference to any one of Figs. 1, 3, 4, 5, 6 and 7 of the accompanying drawings.

12. In an electrical cable having an inner electrical conductor, a conductor shield surrounding said conductor, insulation surrounding said conductor shield and an insulation shield surrounding said insulation, the method of treating said cable for use in low temperatures without introducing damaging stress during cooling in said insulation comprising the steps of sealing one end of said cable, inserting said cable inside a rigid chamber having an inside diameter which is larger than the outside diameter of said insulation shield, heating said rigid cylinder, applying pressure to said cable whereby said insulation and insulation shield expand away from said inner conductor and into engagement with the inner surfaces of said rigid cylinder, and cooling said rigid cylinder while maintaining pressure to said cable.

13. A method of making a coaxial cryogenic cable substantially as described hereinbefore with reference to Fig. 2 of the accompanying drawings.

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